Surface compositional profiles of In(Ga)As quantum rings on GaAs(001)

Stefan Heun[1], Giorgio Biasiol[2], Rita Magri[3], Andrea Locatelli[4], Tevfik Onur Mentes[4], Lucia Sorba[1]

1. NEST INFM-CNR and Scuola Normale Superiore, I-56126 Pisa, Italy
2. Laboratorio Nazionale TASC INFM-CNR, AREA Science Park, I-34012 Trieste, Italy
3. S3 INFM-CNR and Università di Modena e Reggio Emilia, I-41100 Modena, Italy
4. Sincrotrone Trieste S.C.p.A., I-34012 Trieste, Italy

Recent advances in the epitaxial growth of semiconductor nanostructures with techniques such as molecular beam epitaxy have made it possible to form self-assembled nanostructures of various geometries. For years, quantum dots (QD) have epitomized such structures, but recently much attention has also been dedicated to torus-volcano shaped quantum rings (QR) [1], which are formed when QDs are capped in appropriate conditions with a few nanometers of the substrate material, followed by an annealing step at the growth temperature.

Regarding the formation mechanism of QRs, a number of experimental studies were concerned with the geometry of as-grown rings in the InAs/GaAs system, while only a few studies of the composition distribution have been performed by cross-sectional scanning tunneling or transmission electron microscopies on structures buried under a thick GaAs overlayer [2, 3]. A direct measurement of the composition profile in as-grown, unburied rings, as presented here, is thus complementary to such cross-sectional studies and therefore needed for a full quantitative understanding of their formation mechanism.

Using a recently developed technique [4], we have studied the composition profile of self-assembled In(Ga)As QRs grown on GaAs(001). Two-dimensional surface maps obtained by X-ray photoemission electron microscopy (XPEEM) reveal a non-uniform profile with an In-rich core, corresponding to the central hole of the ring, surrounded by a rim with stronger In-Ga intermixing (as shown in Fig. 1). These results are substantiated by an atomistic Valence Force Field (VFF) model which, for a given shape, identifies the composition distribution that minimizes the elastic energy of the system. The VFF calculation predicts a preference for the In atoms to remain localized in the ring hole, in agreement with the experimental findings.

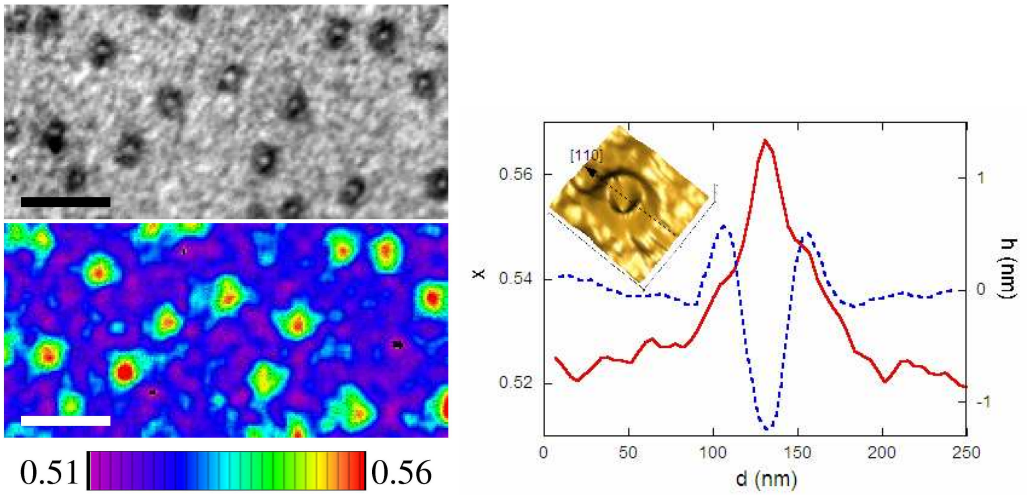

Fig. 1 (a) 1000 nm x 480 nm low-energy electron microscopy (LEEM) image of self-assembled In(Ga)As QRs. (b) Surface In composition of the same area measured by XPEEM. The length markers correspond to 200 nm. (c) Dashed line: atomic force microscopy (AFM) height profile of a QR along the [110] direction (average over 10 line scans). Solid line: XPEEM In composition profile of a QR along the [110] direction (average over 10 line scans). Inset: AFM image of an In(Ga)As QR.

References

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